

## Flexural behaviour of hybrid fibre reinforced concrete beams: a general review

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### ABSTRACT

Performance of conventional concrete is enhanced by the addition of fibres in concrete. The brittleness in concrete is reduced and the adequate ductility of concrete is ensured by the addition of fibres in concrete. In this paper the behaviour of RC beam structures strengthened by using hybrid fibre reinforced concrete (HFRC) is analyzed. The use of two or more types of fibres in a suitable combination may potentially improve the overall properties of concrete and also result in performance concrete. Most PET bottles used as beverage containers become waste after their usage, causing environmental problems. To address this issue, a method to recycle wasted PET bottles is presented, in which short fibres made from recycled PET are used within structural concrete. The fibres used are polyethylene Terephthalate and steel (crimped) fibres in various volume fractions. The main reasons for adding steel fibres to concrete matrix is to improve the post-cracking response of the concrete i.e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. The base polyethylene Terephthalate is highly resistant to the majority of aggressive agents and will never oxidize when exposed to the conditions which cause steel to rust. The literature on beams has been extensively searched for getting platform for the research on the Flexural behaviour of Hybrid fibre (steel and RPET) reinforced concrete is discussed briefly. Finally, general concluding remarks are made along with possible suggestions for future directions of research.

**Key words:** Hybrid Fibre, Reinforced Concrete, Fibre Reinforced Concrete, Recycled Polyethylene Terephthalate, Steel (crimped), Flexural strength, Energy absorption capacity, Ductility, Crack resistance, Crack control.

### 1. INTRODUCTION

Concrete is considered a brittle material, primarily because of its low tensile strain capacity and poor fracture toughness. Concrete can be modified to perform in a more ductile form by the addition of randomly distributed discrete fibres in the concrete matrix. The introduction of fibres for the enhancement of a particular structural behaviour (e.g., shear, impact resistance, behaviour at service load, crack control, etc.) can limit its ductility under flexure. In Fibre Reinforced Concrete (FRC), fibres can be effective in arresting cracks at both macro and micro levels (Albert Meda et al., 2012). For an optimal response, different type of fibres may be suitably combined to produce Hybrid Fibre Reinforced Concrete (HFRC). The use of optimized combinations of two or more types of fibres in the same concrete mixture can produce a composite with better engineering properties than that of individual fibres. This includes combining fibres with different shapes, dimensions, tensile strength and young's modulus to concrete matrices (Eswari et al., 2008). However, appropriate blends of fibres, with or without, traditional reinforcing bars can lead to synergetic effects, i.e. combinations of different fibre types can enhance concrete in both its fresh and hardened states (Ramadevi et al., 2012). Recent years have seen considerable interest in the fibre hybridization – particularly combinations of metallic and non-metallic fibres. For optimal behaviour, different types of metallic and non-metallic fibres have been combined (Singh et al., 2010). The different types of fibres such as steel fibres, macro, micro, monofilament and staple type polypropylene fibres, mesophase pitch based and isotropic pitch based carbon fibres, glass fibres, polyester fibres and polyethylene fibres have been combined in different proportions in order to obtain superior mechanical properties as compared to mono fibre concrete mixes (Singh et al., 2011). However, hybridization consisting of steel fibres and polypropylene fibres has been the most popular fibre combination employed by the researchers. This paper mainly explains the behaviour of RC beams strengthened by using hybrid fibre reinforced concrete is analyzed. The two types of fibres used are Steel (crimped) and Recycled Polyethylene Terephthalate Fibres in the proportions like 0.5%, 1.0%, 1.5% and 2.0% and the tested results were compared with the control specimens (Ramadevi et al., 2012).

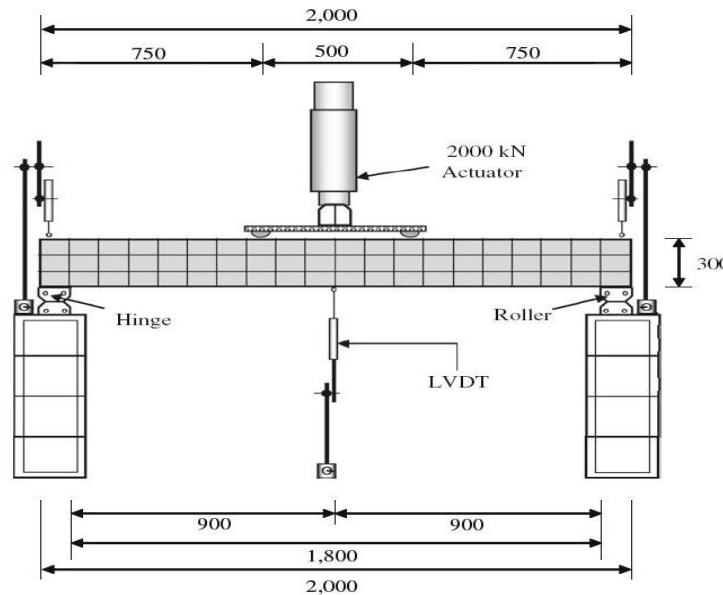
### 2. EXPERIMENTAL PROGRAMME

#### 2.1. Test specimens

In order to investigate the fibre contribution to the flexural behaviour of RC elements, seven full-scale beams have been tested up to failure under a four-point loading scheme. All samples were 4m long with a span of 3.6m and a depth of 300mm (the effective depth was 260 mm) (Alberto Meda et al., 2012). 100 x 100 x 500 mm prisms were tested in a loading frame. The test program was designed to study the ductility performance of concrete specimens with and without fibres, (Eswari et al., 2008). Fourteen beams with dimensions of 150 x 250 x 2400 mm (width x depth x length) are fabricated for testing. All beams are reinforced internally with 13 mm diameter deformed high-tensile steel bars at an effective depth 203.5mm. The beams are sufficiently reinforced against shear failure by using high strength steel deformed bar of 10 mm diameter at a spacing of 100 mm center to center, (Hee Sun Kim et al., 2011). To study and compare the flexural behaviour of reinforced SCC beams without fibres, with macro fibres and with hybrid fibres, three beams each of 125 mm width, 200 mm depth and 1200 mm

length were cast for all the three designed mixes. These under reinforced beams were hypothetically reinforced with three 10 mm diameter bars in the tension zone. Shear reinforcement in the form of 8mm diameter stirrups were provided at a spacing of 130 mm centre to centre, (Jeenu et al., 2007). Tested for each concrete mixture, five 100 x 100 x 500 mm prismatic specimens were cast. The concrete was placed in each mould in two layers. After each layer, the mould was placed on a vibrating table for compaction. There was no difficulty in moulding the specimens; all mixes flowed easily under an external vibration (vibrating table). Specimens were demoulded after 24 hours and then placed in a curing room with 100% relative humidity and 20° C temperatures until the day of testing. These prismatic specimens were used to determine the flexural properties, i.e. modulus of rupture (MOR), residual flexural tensile strength (RFTS) and flexural toughness (FT), (Rashid Hameed et al., 2010). The performances of HSC beams with and without fibres, by flexure test using third-point loading. The beams of 150 mm x 250 mm in cross section and over all span of 3000mm provided with 2 nos. 12 mm rebar on tension zone and shear reinforcement of 8mm at 150 mm centre were used, (Ravichandran et al., 2008). A total of eight rectangular reinforced concrete beams were investigated, one reinforced with steel bars (B1), one reinforced with GFRP bars (B2), and six beams reinforced with a combination of steel and GFRP bars (Wenjun Qu et al., 2009).

## 2.2. Test procedure



**Figure 1**  
Test setup and data acquisitions locations (unit: mm)

the beam was kept as simply supported. The beam was divided into number of grids before placing in the loading frame for the observation of crack pattern. The load cell was placed in the loading jack at the centre of the beam from which load imparted to the beam can be observed. For finding the deflections under the one-third loading points, the deflectometers were placed and LVDT was placed in the centre of the beam to measure the mid-deflection. The strain gauges were fixed in top and bottom fibre of beams, from which strains can be obtained. The load cell, LVDT and strain gauges were connected to a 20 channel Data Logger, where the results can be viewed. (Sung Bae Kim et al., 2010) Tested as shown in the schematic test set up fig.1 below for RC beam specimens with hinge-roller supports were tested using UTM with a maximum load capacity of 2000kN.

## 3. DISCUSSION OF RESULTS

The experimental results will be discussed by focusing first on beam behaviour at ultimate limit states and, afterwards, at service load (Alberto Meda et al., 2012). The influence of fibre, under a structural point of view, is quite different in these two conditions, leading to significant design implications (Eswari et al., 2008). The beam specimens were subjected to two point bending test in 300 T UTM. The test results show that the load carrying capacity increases with increase in fibre content. The increase in ultimate load was found to be 72.42% with 2.0% hybrid fibre content when compared to that of plain concrete (Ramadevi et al., 2012). The increase in ultimate load capacity was found up to 0.5% hybrid fibres and a decrease in ultimate load was observed when 1% hybrid fibres were used. A constant increase in ultimate load capacity was found from 1.5% to 2.0% hybrid fibre reinforced beams. The maximum ultimate load carrying capacity was found to be 14 kN for 2% hybrid fibres (Rashid Hameed et al., 2010). The results for the representative curves of load-CMOD and load-deflection behaviour of all the concrete mixtures are shown in Figures 4 and 5 respectively, where it can be observed that reinforced matrices exhibit high strength and toughness compared to un-reinforced matrix. It is important to mention here that each representative curve shown here is not an average of five samples. In fact, after plotting the curves of all samples of each composition, a single representative curve was selected. However, the values of each flexural property (i.e. MOR, RFTS and FT) given in the following sections are the average of those from five samples of each composition (Wenjun Qu et al., 2009). The flexural capacity of the hybrid GFRP/steel-reinforced concrete beams increased as the effective reinforcement ratio ( $\rho_{eff}$ ) increased. This indicates that ( $\rho_{eff}$ ) is a reasonable parameter for the flexural capacity of hybrid GFRP/steel-reinforced concrete beams. The axial stiffness ratio of reinforcement ( $R_f$ ) has relatively little influence on the flexural capacity. Even though the  $R_f$  of B4 was about 1.6 times higher than that of B3, B4 only resisted a slightly higher (3.6%) failure load. The observed failure modes of the tested beams are also presented in Table 4. All the hybrid GFRP/steel-reinforced concrete beams failed due to crushing of the concrete in the compressive zone after the steel bars yielded, while the stress of the GFRP bars reached a small percentage of its ultimate value. This failure mode indicates that the balanced effective reinforcement ratio ( $\rho_{eff,b}$ ) is suitable for the control of the flexural failure mode of hybrid GFRP/steel-reinforced concrete beams. The ultimate load carrying capacities predicted by the theoretical and design models are also illustrated in Table 4. The proposed design equations predicted the load carrying capacity of the tested beams reasonably well, except B7 and B8. The predictions of the theoretical analysis were in good agreement with the experimental results for the tested beams, except B8. The accuracies of

the design model and the theoretical analysis for beams with low or high effective reinforcement ratios need further verification.

#### 4. SUMMARY AND CONCLUSIONS

FRC can modify the collapse mode of beams moving the failure from concrete crushing to steel rupture. With this regard, high fibre contents can determine a lower ductility as they lead to an early strain concentration in the rebars. The enhancement in the bearing capacity under flexure due to the addition of fibres strongly depends on the ratio between FRC toughness and the reinforcement ratio: in the beams herein tested, this increment was quite limited. The overall ductility is strongly influenced by fibres, either in positive or negative terms, depending once again on the FRC toughness over the reinforcement percentage ratio. A maximum increase in compressive strength of the order of 18% over plain concrete was observed in case of concrete containing 75% steel fibres + 25% polypropylene fibres. In case of static flexural strength tests, a maximum increase in flexural strength of the order of 84% was observed for HyFRC with 75% steel fibres + 25% polypropylene fibres. The results obtained in this investigation indicate that, in terms of flexural toughness, with fibre combination of 75% steel fibres + 25% polypropylene fibres gives the best performance. The flexural toughness of HSC improved with addition of fibres at various volume fractions. The flexural toughness of HSC containing fibres in hybrid form observed to have more than the HSFRC. Based on the experimental results, the following conclusions are drawn for HFRC beams with subjected to flexural loading.

1. The percentage of fibres used was 0.5%, 1%, 1.5% and 2% and the results were compared with the control beam specimen.
2. Tension cracks were formed in both RC beams and HFRC beams under the loaded area.
3. The ultimate deflection for the HFRC beams was found to be increasing when compared to the control specimen, which is due to the increase in ductility of the beams by the introduction of fibres.
4. The deflection of the mid-span for control beam and gradually decreased up to 2.0% HFRC beams which indicate the decrease in mid-span deflection with an increase in hybrid fibre proportion.

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